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EROSION OF NICKEL ALUMINIDE

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MTL 89-30(TR)

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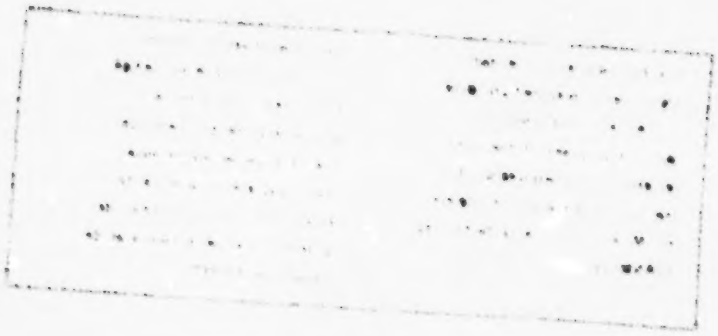

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METALS TECHNOLOGY LABORATORIES
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EROSION OF NICKEL ALUMINIDE

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A.W. Lui and J. McGoey

ABSTRACT

The erosion resistance of three nickel aluminide alloys was studied in the laboratory and was compared with that of stainless steel 304 and alloy 800H. The effect of oxygen potential, erosion temperature and impingement angle was also investigated. It was found that the erosion resistance of the alloys is similar to that of SS 304, but slightly better than that of alloy 800H. Raising the erosion temperature from 25°C to 600°C or replacing N_2 by air as carrier gas for erodant has no significant effect on wear rate. However, the rate was significantly reduced by changing the impingement angle from 30° to 90°.

LABORATOIRES DE LA TECHNOLOGIE DES MÉTAUX
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ÉROSION DE L'ALUMINIURE DE NICKEL

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RÉSUMÉ

La résistance à l'érosion de trois alliages d'aluminiure de nickel a été étudiée en laboratoire et comparée à celle de l'acier inoxydable 304 et de l'alliage 800H. L'effet du potentiel de l'oxygène, de la température d'érosion et de l'angle d'incidence a aussi été examiné. On a trouvé que la résistance à l'érosion des alliages est voisine de celle de l'acier inox 304, mais légèrement supérieure à celle de l'alliage 800H. L'élévation de la température d'érosion de 25 à 600°C ou le remplacement de N_2 par de l'air comme gaz vecteur pour l'agent érodant n'a pas d'effet sur le taux d'usure. Cependant, ce dernier a sensiblement diminué quand on a fait passer l'angle d'incidence de 30 à 90°.

INTRODUCTION

Nickel aluminide (Ni_3Al) was developed as a substitute for Cr-containing alloys used as structural materials for high-temperature application (1-3). Its mechanical properties and corrosion properties have been studied extensively (4-7). Single crystal Ni_3Al has a unique property of increasing yield strength with increasing test temperature and possesses excellent ductility. Polycrystalline Ni_3Al is brittle and can be ductilized by addition of boron. The alloy has excellent oxidation resistance. In an air environment, the alloy developed predominantly nickel oxide. In a low oxygen potential environment, aluminum oxide formed. It is important to know the erosion behaviour of the alloy. In this work, the effect of erosion temperature and oxygen potential of environment on erosion behaviour of the material is investigated. We also want to know whether the alloy behaves as a ductile or brittle material during high temperature erosion and its erosion resistance compared with that of SS304 and alloy 800H.

EXPERIMENTAL

APPARATUS

The erosion tester used in this work consisted of specimen testing chamber, gas preheater, particle feeder and microprocessor. The microprocessor controls and measures the sample temperature, gas flow rate, particle velocity and duration of test. During testing, the gas-particle stream accelerates along a tube inside the preheater furnace and is heated to a desired temperature before it strikes the sample in the specimen chamber. Inside the specimen chamber, samples can be pre-set at a desired impingement angle (0-90°) for testing.

MATERIAL

Three compositions of nickel aluminide produced by electroslag casting and the twin-roll casting process in the Foundry Section of the Metals Technology Laboratories (MTL) are shown in Table 1. The alloys were cut into 2.5 x 3 cm coupons, polished to 240-600 grit finish before mounting in the erosion tester for investigation. Industrial silicon carbide grains of size 180 μm were used as erodant. They were fed at 10 g/m accelerating to a velocity of 26 m/s during the test. The erosion rate was calculated by weight loss of specimen per unit increment of erodant.

During the experiment, the effect of temperature was achieved by varying the erosion temperature from 25 to 600°C, and the effect of oxygen potential was achieved by replacing N_2 with air as carrier gas for erodant. Two impingement angles, 30° and 90°, were studied to see if the material eroded as a brittle or as a ductile material at high temperature.

RESULTS AND DISCUSSION

Results summarized in Tables 2 and 3 showed that, under identical conditions, the wear rate of the cold-rolled alloys are always higher than that of the annealed ones. Under steady-state erosion, the rates of all three alloys are comparable and are similar to that of SS 304, but are slightly lower than that of alloy 800H for a given increment of particles. When nitrogen was replaced with air as carrier gas or when the erosion temperature increased from 25 to 600°C, there is no significant difference in wear rate. Since Ni_3Al alloy has excellent resistance to oxidation at high temperature, the results suggested that, at 600°C, the oxidation rate in air is too small for oxide scale either to modify the substrate behaviour or to contribute significantly to wear loss.

Tables 4 and 5 present the results of studies when erodant particle streams strike the metal surfaces at two impingement angles (30 and 90°). At 25°C and 600°C, the wear rates at a 30° impact angle are always higher than those at a 90° impact angle. This phenomenon is an indication of the classical ductile erosion behaviour of material (8) in that erosion loss decreases as the angle of impingement increases, whereas for brittle material erosion loss will increase as the angle of impingement increases.

The surface morphology of the eroded specimen was examined by SEM. As shown in Fig. 1-4, alloy 3B1 (annealed and cold rolled) eroded in air, and nitrogen had shallow crater formation on its surface, which is the appearance of a ductile surface eroded by platelet mechanism (9). No fracture of surface scale was observed. Figures 5-8 show the eroded surfaces of alloys IC-50 and IC-218 both annealed in air and nitrogen. Essentially, there is no difference in appearance of the surface texture between the eroded specimens.

CONCLUSIONS

Three nickel aluminide alloys were tested in the laboratory erosion tester, it was found that:

1. at 25°C or 600°C, in a nitrogen or air atmosphere, with silicon carbide as the erodant at 26 m/s, there is no significant difference in erosion rate between the three alloys.
2. all three nickel aluminide alloys showed a higher erosion rate with the cold-rolled alloys than with the annealed alloys.
3. raising the erosion temperature from 25 to 600°C and replacing nitrogen by air as carrier gas for the erodant do not significantly affect the erosion rates of the alloys.
4. all of the nickel aluminide alloys, whether annealed or cold rolled, behave as ductile metal at both 25 and 600°C as is evident by the significant reduction in erosion rate at an impact angle of 90° compared with an impact angle of 30°.

5. at 600°C, the erosion resistance of the Ni_3Al alloys in air or in nitrogen is similar to that of SS 304 but slightly better than that of alloy 800H.

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Table 1. Composition of nickel aluminide alloys (wt %)

Alloy	Al	Cr	Zr	B	Ni
3B1	10.6	--	--	0.009	88.8
IC-50	11.3	--	0.6	0.02	88.1
IC-218	8.5	7.8	0.8	0.02	82.8

Table 2. Erosion rate of Ni_3Al alloys in air and N_2 atmosphere at 600°C and 30° impingement angle (g of metal loss per 100 g of erodant used).

	Nitrogen	Air
3B1 annealed	4.0×10^{-4}	4.0×10^{-4}
3B1 cold rolled	4.3×10^{-4}	4.5×10^{-4}
IC-50 annealed	3.8×10^{-4}	3.8×10^{-4}
IC-50 cold rolled	4.3×10^{-4}	4.0×10^{-4}
IC-218 annealed	3.9×10^{-4}	3.8×10^{-4}
IC-218 cold rolled	4.3×10^{-4}	3.9×10^{-4}
SS 304H	4.2×10^{-4}	4.2×10^{-4}
800H	4.5×10^{-4}	4.9×10^{-4}

Table 3. Erosion rate of Ni_3Al alloys at 25°C and 600°C and 30° impingement angle under an N_2 atmosphere (g of metal loss per 100 g of erodant used).

	600°C	25°C
3B1 annealed	4.0×10^{-4}	3.7×10^{-4}
3B1 cold rolled	4.3×10^{-4}	4.0×10^{-4}
IC-50 annealed	3.8×10^{-4}	4.0×10^{-4}
IC-50 cold rolled	4.3×10^{-4}	4.2×10^{-4}
IC-218 annealed	3.9×10^{-4}	4.0×10^{-4}
IC-218 cold rolled	4.3×10^{-4}	4.3×10^{-4}
SS 304H	4.2×10^{-4}	3.7×10^{-4}
800H	4.5×10^{-4}	4.2×10^{-4}

Table 4. Erosion rate of Ni_3Al alloys at 30° and 90° impingement angles under an N_2 atmosphere at 600°C (g of metal loss per 100 g of erodant used).

	30° angle	90° angle
3B1 annealed	4.0×10^{-4}	2.3×10^{-4}
3B1 cold rolled	4.3×10^{-4}	2.7×10^{-4}
IC-50 annealed	3.8×10^{-4}	2.3×10^{-4}
IC-50 cold rolled	4.3×10^{-4}	2.5×10^{-4}
IC-218 annealed	3.9×10^{-4}	2.2×10^{-4}
IC-218 cold rolled	4.3×10^{-4}	2.6×10^{-4}

Table 5. Erosion rate of Ni_3Al alloys at 30° and 90° impingement angles under an N_2 atmosphere at 25°C (g of metal loss per 100 g of erodant used).

	30° angle	90° angle
3B1 annealed	3.7×10^{-4}	2.3×10^{-4}
3B1 cold rolled	4.0×10^{-4}	2.5×10^{-4}
IC-50 annealed	4.0×10^{-4}	2.4×10^{-4}
IC-50 cold rolled	4.2×10^{-4}	2.2×10^{-4}
IC-218 annealed	4.0×10^{-4}	2.4×10^{-4}
IC-218 cold rolled	4.3×10^{-4}	2.5×10^{-4}

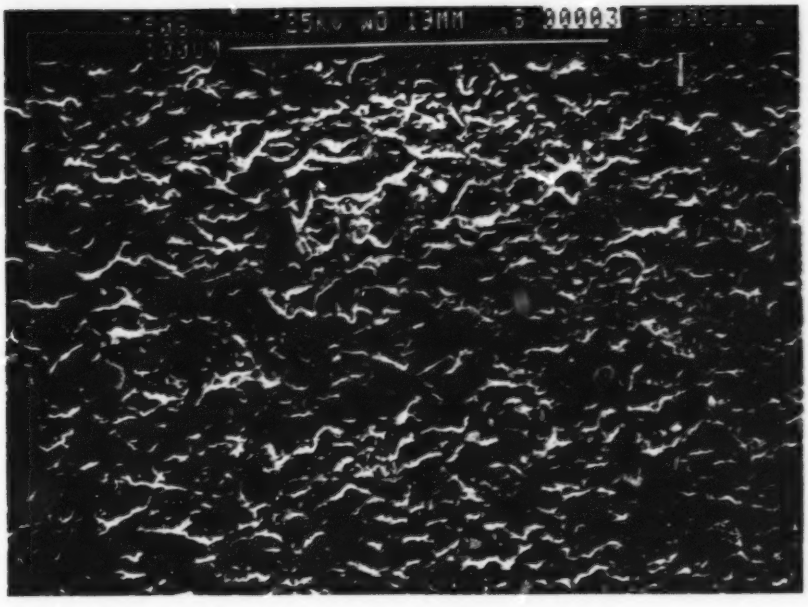

Fig. 1. Surface morphology of annealed alloy 3B1 after erosion in air at 600°C for 20 h. (neg 19714)

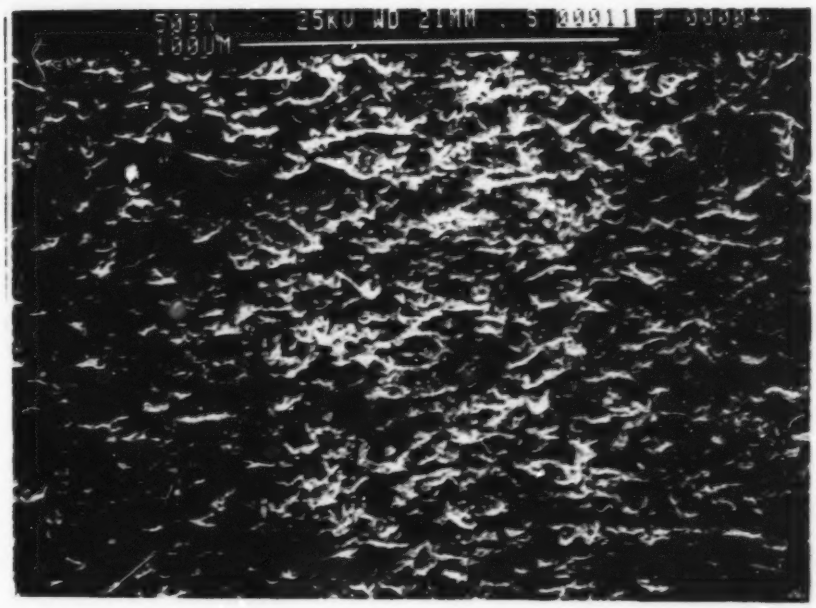

Fig. 2. Surface morphology of annealed alloy 3B1 after erosion in N_2 at 600°C for 20 h. (neg 19715)

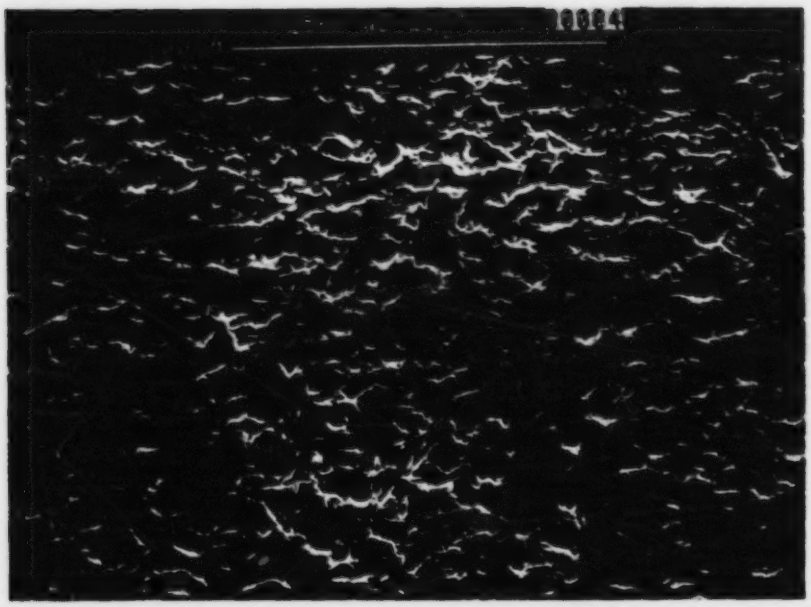

Fig. 3. Surface morphology of cold rolled alloy 3B1 after erosion in air at 600°C for 20 h. (neg 19716)

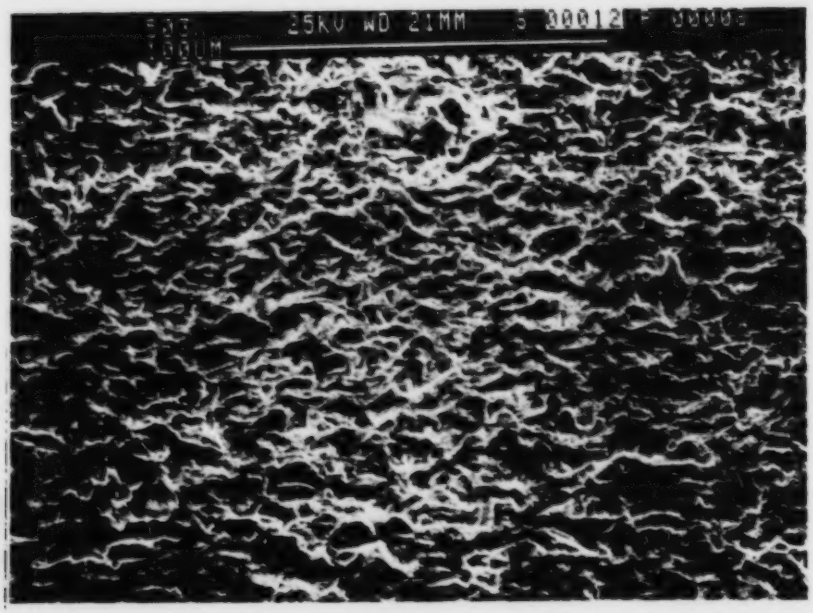

Fig. 4. Surface morphology of cold rolled alloy 3B1 after erosion in N_2 at 600°C for 20 h. (neg 19713)

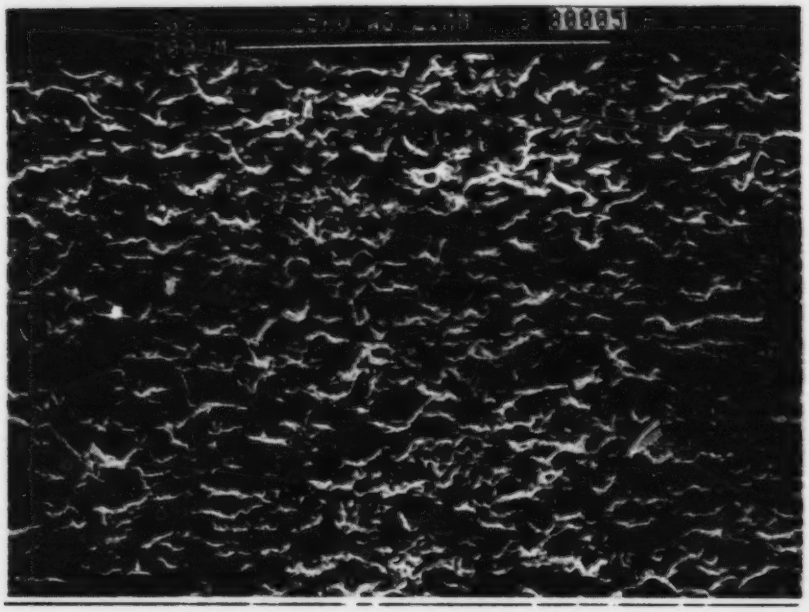

Fig. 5. Surface morphology of annealed alloy IC-50 after erosion in air at 600°C for 20 h. (neg 19709)

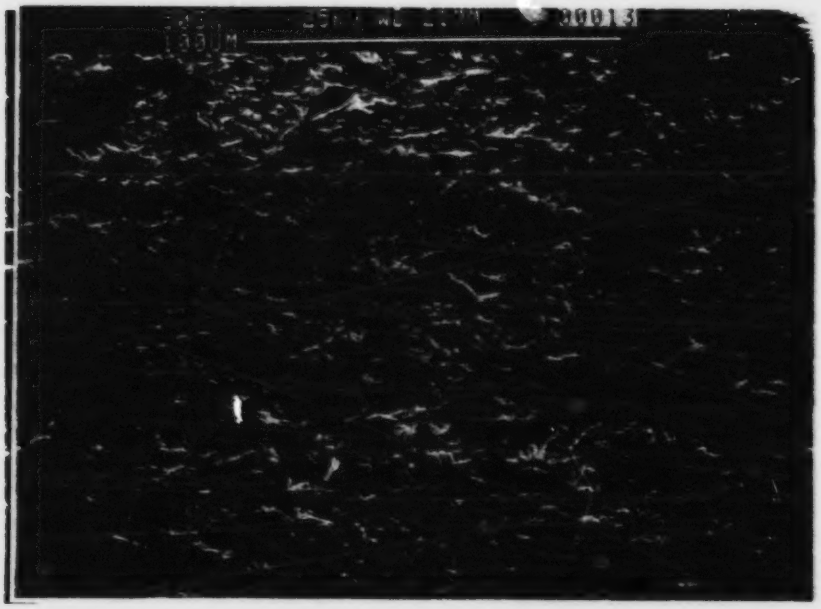

Fig. 6. Surface morphology of annealed alloy IC-50 after erosion in N_2 at 600°C for 20 h. (neg 19711)

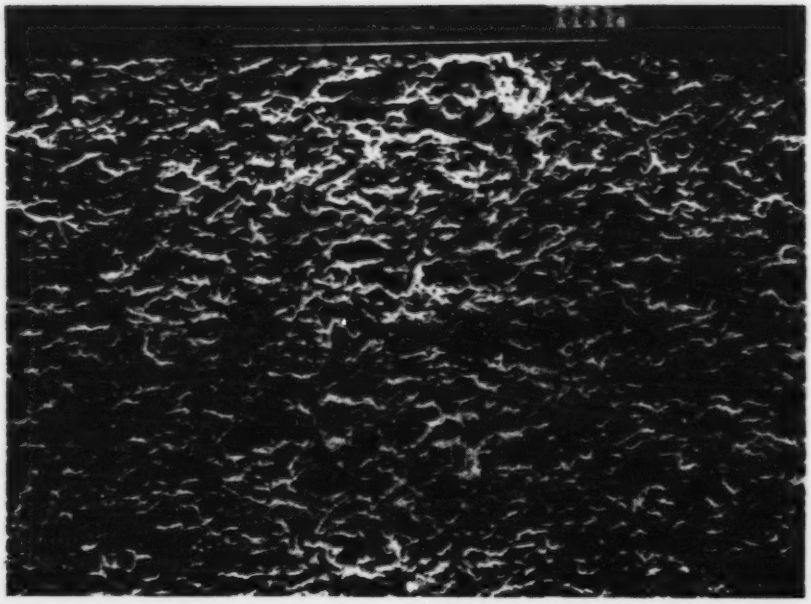

Fig. 7. Surface morphology of annealed alloy IC-218 after erosion in air at 600°C for 20 h. (neg 19710)

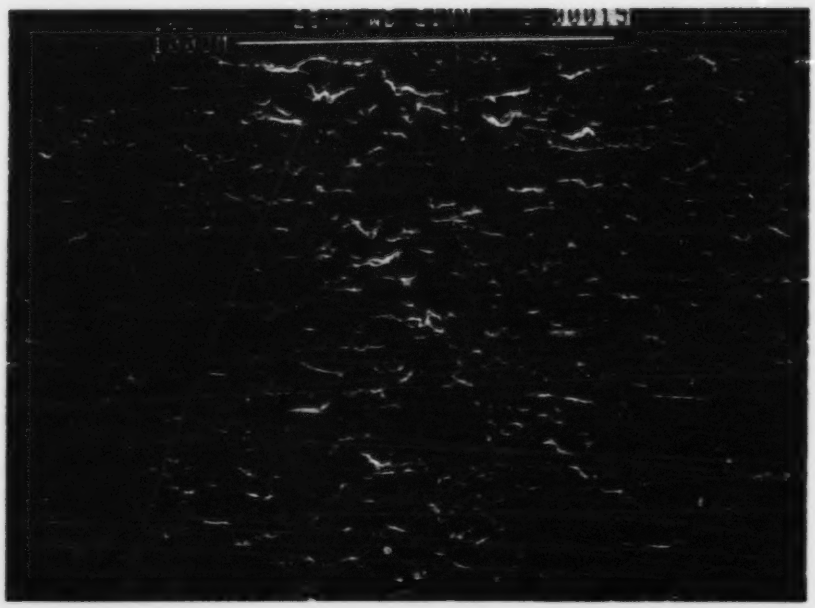

Fig. 8. Surface morphology of annealed alloy IC-218 after erosion in N_2 at 600°C for 20 h. (neg 19712)